

IN THE SPECIFICATION:

Please replace paragraph number [0013] with the following rewritten paragraph:

[0013] In accordance with one aspect of the present invention, a propulsion system in the form of a rocket motor offering extended mission time, intermittent operability and steerability is provided. The rocket motor includes a pressure vessel containing a solid propellant in communication with a selectively controllable axial thrust valve operably coupled with an axial thruster and selectively controllable maneuver control valves operably coupled with one or more maneuver control thrusters. Maneuver control capabilities may include pitch, yaw and roll and, as used herein, the term “maneuver control” includes alteration ~~of~~ of, or the capability for ~~altering~~ altering, one or more of the foregoing positional parameters of the rocket motor and associated payload, which may in combination also be termed the “vehicle.” The axial thrust valve and maneuver control valves may comprise proportional, or throttling, type valves configured to provide one or more partially open operational modes between full open and full closed. As used herein, the term “proportional valve” includes a valve having at least one partially operational mode between full open and full closed. The axial thruster and some or all of the maneuver control thrusters may be operated separately or simultaneously. The cross-sectional exit area through the axial thrust valve may be selectively reduced during operation of the maneuver control thrusters to maintain a substantially constant axial thrust and, thus, vehicular velocity. The solid propellant mass may be sized to provide axial thrust of a desired magnitude and duration while also providing thrust for maneuver control.

Please replace paragraph number [0026] with the following rewritten paragraph:

[0026] One exemplary embodiment of a rocket motor according to the present invention, which may comprise an upper or final stage rocket motor, is depicted in FIG. 1. The motor case assembly comprises a motor case housing 12 which houses the pressure vessel 14 (also sometimes termed a “motor case”) having a plurality of valves in communication therewith. Within the pressure vessel 14, low density foam 20 surrounds and insulates the solid propellant grain 22. In one exemplary, nonlimiting implementation of the present invention, the motor case

assembly within motor case housing 12 may have a diameter 16 of between about 25 and 30 inches, currently preferred to be 27.6 inches and a length 18 of between 30 and 35 inches, currently preferred to be 32 inches. Solid propellant grain 22 may comprise, for example, a free standing class 7 HMX (cyclotetramethylenetetranitramine)-oxidized composite propellant with a binder system based on hydroxyl-terminated polybutadiene (HTPB) polymer and cured with isophorene diisocyanate (IPDI) curative including a small amount of carbon black as an opacifier, the propellant being formulated to burn stably over a wide pressure range. Alternatively, solid propellant grain 22 may comprise, for example, an aluminum powder-fueled, hydroxyl-terminated polybutadiene (HTPB) polymer-based binder. One currently preferred propellant is a ~~non~~-nonaluminized HTPB propellant grain of 228 lbm for the above-sized rocket motor. The solid propellant chosen for use may be any of those known to one of ordinary skill in the art, as the present invention does not require a specific propellant for implementation.

Please replace paragraph number [0027] with the following rewritten paragraph:

[0027] The axial thrust valve 10 may comprise a pintle valve configured for proportional operation and control of axial thrust through axial thruster 26, which may be configured, by way of example only, to provide a maximum of 4,000 lbf of thrust. As best observable from FIG. 2, which illustrates the exit cone 24 of axial thruster 26 in broken lines for clarity, ~~attitude~~ maneuver control thrusters 32, 34, 40a, 40b, 42a, 42b are respectively operably coupled to maneuver control valves 28, 30, 36a, 36b, 38a, 38b and located and oriented to effect maneuvering functions including pitch, yaw and roll control. Maneuver control valves 28, 30, 36a, 36b, 38a, 38b may comprise proportional valves. As depicted in FIGS. 2 and 3, selective operation of two maneuver control valves 28, 30 with respectively associated coplanar maneuver control thrusters 32, 34 located 180° apart and oriented transverse to the longitudinal axis L of the rocket motor may be used for pitch control. Yaw control may be effected by selective operation of either paired maneuver control thrusters 40a and 42a by maneuver control valves 36a and 38a or paired and diametrically opposed maneuver control thrusters 40b and 42b by maneuver control valves 36b and 38b. As shown, paired maneuver control thrusters-~~36a~~ 40a and ~~38a~~ 42a and ~~36b~~ 40b and ~~38b~~ 42b are coplanar, oriented transverse to longitudinal axis L of

the rocket motor and may be ~~used~~ used to provide balanced, parallel thrust vectors to either side of longitudinal axis L at identical lateral offsets therethrough. Roll control may be effected by selectively using two sets of maneuver control valves 36a, 36b, 38a, 38b and respectively associated coplanar ~~attitude~~ maneuver control thrusters 40a, 40b, 42a, 42b. Roll in a first rotational direction may be effected by opening maneuver control valves 36a and 36b to power maneuver control thrusters 40a and 40b and cause them to provide a first set of opposing but complementary thrust vectors laterally offset from longitudinal axis L, while roll in a second direction may be effected by opening maneuver control valves 38a and 38b to power maneuver control thrusters 42a and 42b and cause them to provide a second set of opposing but complementary thrust vectors laterally offset from longitudinal axis L.

Please replace paragraph number [0029] with the following rewritten paragraph:

[0029] With all of the attitude control valves closed, higher operating pressure within pressure vessel 14 and correspondingly higher thrust may be accomplished by partially closing the axial thrust valve 10. Partially closing the axial thrust valve 10 will reduce the effective cross-sectional area of the nozzle throat 48, resulting in a higher operating pressure and therefore higher thrust. This will decrease the mission time. As noted above, the axial thrust valve 10 may comprise a pintle valve, with actuator 44, powered by battery 46 moving the pintle element 50 toward and away from the nozzle throat 48 to change the nozzle throat area to alter pressure within the pressure vessel 14 and resulting thrust. While only a single axial thrust valve and associated axial thruster are depicted in the foregoing embodiment, it is contemplated that more than one axial thrust valve and associated axial thruster may be employed without departing from the scope of the present invention. Maneuver control valves 28, 30, 36a, 36b, 38a and 38b may, as with axial thrust valve 10, be actuated by battery-powered actuators (not shown) powered by battery 46 or one or more other batteries. Alternatively, the valves, if electrically actuated, may be powered by a fuel cell. Thrust to any one of the maneuver control or axial thruster valves may be controlled proportionately and substantially independently of the thrust provided to any other thruster valves. For example, the thrust provided to maneuver control (pitch) thruster 32 by maneuver control valve 28 may be set to 100 lbf while all other maneuver control valves are

producing a negligible amount of thrust through their associated thrusters. Then, to increase thrust in, for example, the yaw direction while maintaining the thrust in the pitch direction, maneuver control (yaw) valves 36a and 38a may be opened and maneuver control valves 30, 36b and 38b may be closed further. By closing the maneuver control valves 30, 36b and 38b further, the pressure in pressure vessel 14 is increased to increase mass flow. By opening maneuver control (yaw) valves 36a and 38a further, more mass flow is directed out of those valves into their associated yaw maneuver control thrusters 40a and 42a, producing increased thrust. Mass flow and, therefore, burn time, may also be controlled substantially independently of other system variables. For example, a null thrust and low mass flow scenario may be created by opening all of the valves to the point where all thrusts are offsetting and a minimum steady state mass flow exists. To increase mass flow and keep maneuver thrust the same, all valves may be closed partially to increase pressure in the pressure vessel 14, thereby increasing mass flow. Minimization of mass flow while meeting other system requirements is the generally preferred operational state.

Please replace paragraph number [0032] with the following rewritten paragraph:

[0032] The maneuver control thrusters for pitch, yaw and roll may, instead of being aimed transversely to the longitudinal axis L of the rocket motor, be oriented to release gases substantially in the direction of axial thrust (not shown). Thus, pitch yaw and roll control thrusters may be individually offset from the longitudinal axis L of the rocket motor; however, these maneuver control thrusters may, for example, be located and oriented to collectively form a concentric ring about the longitudinal ~~axis~~ axis L of the rocket assembly, so that simultaneous operation of certain or all of the associated maneuvering valves causes the maneuver control thrusters to provide thrust to the vehicle without adjustment in pitch, yaw or roll. In such a configuration, and if the maneuver control thrusters may provide sufficient axial thrust, the presence of a separate, main axial thrust valve to provide axial thrust is optional.

Please replace paragraph number [0033] with the following rewritten paragraph:

[0033] ~~FIG. 3~~FIG. 3 illustrates one mode of operation of the solid propellant propulsion system of FIG. 1 to effect pitch control. Opening maneuver control valve 28 (~~See also Figure~~ FIG. 1) will produce a thrust through maneuver control thruster 32 in the direction depicted by direction arrow 52. Influence of the yaw of the vehicle, illustrated in FIG. 4, may be effected in another mode of operation by opening maneuver control valves 36b and ~~38b~~ 38b to produce parallel thrust vectors from thrusters 40b and 42b in the direction depicted by arrows 58, 60.

Please replace paragraph number [0034] with the following rewritten paragraph:

[0034] Roll control may be achieved by the mode of operation illustrated in FIG. 5. Opening two maneuver control ~~valves~~ valves, such as valves 36a and 36b to respectively power opposing, off-axis maneuver control thrusters 40a and ~~40b~~ 40b, produces offset thrust about longitudinal axis L in a common plane transverse to longitudinal axis L in directions 62 and 64, causing the vehicle to roll in a clockwise direction 66. With the addition of propellant mass above that which is required for axial thrust, maneuvering functions can thus be performed without affecting axial thrust levels. The maneuver control thrusters may be smaller than the axial thruster 26, with each maneuver control thruster 32, 34 for pitch control and each maneuver control thruster of the two sets of yaw and roll maneuver control thrusters 40a, 40b and 42a, 42b providing a smaller force than the axial thruster 26. For ~~example~~ example, and not by way of limitation, maneuver control thrusters 32 and 34 for pitch control may be designed to each provide 1,000 lbf maximum thrust capability, while maneuver control thrusters 40a, 40b, 42a and 42b for yaw and roll control may each be designed to provide a 500 lbf maximum thrust capability.

Please replace paragraph number [0036] with the following rewritten paragraph:

[0036] FIGS. 9 through 11 illustrate yet another exemplary embodiment of the invention and the configuration of maneuver control valves 92a, 92b, 96a, 96b, 98a, 98b, 100a and ~~110b~~ 100b and associated maneuver control thrusters T thereof. In this embodiment, thrusters T may each comprise, for example, a thruster designed to provide 500 lbf of thrust.

FIG. 9 depicts one mode of operation for controlling pitch of the vehicle. The pair of maneuver control valves 92a and 92b is opened to create a force in direction 94. FIG. 10 shows adjustment of yaw of the vehicle in another mode of operation by opening maneuver control valves 96a and 96b for creating thrust in direction 102. Roll control, pictured in FIG. 11, may be achieved by opening two, off-axis maneuver control valves 96a and 100b in yet another mode of operation to produce thrust in the opposing and parallel but laterally offset directions depicted by arrows 104 and 106, causing the vehicle to roll in a clockwise direction 108.

Please replace paragraph number [0039] with the following rewritten paragraph:

[0039] FIG. 14 depicts, in schematic form, an exemplary configuration for a hybrid rocket engine. Details of the structure of and suitable propellants, oxidizers and ignition sources for use in, such a hybrid rocket engine are known to those of ordinary skill in the art, and may also be found, for example, in U.S. Patent 6,393,830, assigned to the assignee of the present invention and the disclosure of which patent is incorporated herein by reference. A hybrid rocket engine according to the present invention may comprise a pressure vessel 114 containing a suitable solid propellant grain 122. Pressure vessel 114 is in selective communication with an axial thruster 126 through axial thrust valve 110 and in selective communication with a plurality of maneuver control thrusters 130 for pitch, yaw and roll control through respectively associated maneuver control valves 128. Any suitable number of maneuver control valves 128 and associated maneuver control thrusters 130 may be employed as desired or required, depending on the maneuver control thruster layout chosen. Axial thrust valve 110 and maneuver control valves 128 may comprise proportional, or throttling type valves. An oxidizer source 200 is disposed in selective communication with pressure vessel 114 through control valve 202, which may comprise a proportional, or throttling type valve. An ignition fluid source 210 is also disposed in selective communication with pressure vessel 114 through control valve 212, which may also comprise a proportional, or throttling type valve. Combustion of solid propellant grain 122 may be initiated by starting flow of oxidizer from oxidizer source 200 in combination with ignition fluid from ignition fluid source 210. Operation of the hybrid rocket engine for axial thrust and maneuver control may be conducted generally as described with respect to the solid

rocket motor embodiments herein. However, termination of combustion of solid propellant grain 122 may be terminated by terminating flow of oxidizer from oxidizer source 200 by closing control valve ~~2002~~ 202. Combustion of solid propellant grain 122 may be reinitiated by restarting flow of oxidizer from oxidizer source 200, as desired and, where combustion has been terminated for an extended period of time, by supplying ignition fluid from ignition fluid source 210. The present invention may also be implemented in the form of a so-called “reverse” hybrid rocket engine, as disclosed in the aforementioned patent, wherein a solid oxidizer grain may be employed in pressure vessel 114 and a flowable source of propellant selectively supplied thereto. Therefore, as used herein, the term “hybrid” rocket engines ~~includes~~ include both types.

Please replace paragraph number [0040] with the following rewritten paragraph:

[0040] Referring again to FIGS. 1 and 2, axial thrust termination may be accomplished by closing down the axial thrust valve 10 while simultaneously opening all maneuver control valves 28, 30, ~~36~~ 36a, 36b, and ~~38~~ 38a and 38b. All combustion gases will vent radially from pressure vessel 14, in equal and opposite directions, balancing any forces which would result in the vehicle deviating from its intended path. During this axial thrust termination phase, sufficient pressure exists within pressure vessel ~~for 14~~ for continued burning of the solid propellant grain 22.

Please replace paragraph number [0041] with the following rewritten paragraph:

[0041] If desired, the solid propellant grain 22 may be extinguished at an appropriate time to preserve fuel for use at a later time. Fully opening all valves, comprising the axial thrust valve 10 in combination with all maneuver control valves such as 28, 30, 36a, 36b, 38a and 38b, will cause rapid depressurization of the pressure vessel 14. The resulting reduced pressure within pressure vessel 14 will extinguish the solid propellant grain 22. However, sufficient thermal mass, aided by the presence of ~~insulation~~ low density foam 20, and continued ablation exists within the motor case 14 to provide the necessary conditions for reignition at a later time. Closing all valves will increase the pressure within the motor case 14 and reignite the solid

propellant grain 22. The ability to shut down and restart the rocket motor results in a theoretically infinite number of possible duty cycles which can be carried out on demand.

Please replace paragraph number [0043] with the following rewritten paragraph:

[0043] After an extended time delay subsequent to extinguishment of a propellant grain, the amount of residual heat in the rocket motor may be insufficient for reignition to occur. Yet another exemplary embodiment of the present invention, depicted in FIG. 13, includes a rocket motor offering the capability to initiate a plurality of pulses without regard to time delay. A first solid propellant grain 68 may fire until extinguished or burned out, producing a first pulse in isolation from second solid propellant grain 70 due to the interposition of flame-inhibiting barriers~~74~~ 174 associated with solid propellant grains 68 and 70, then the second solid propellant grain 70 may be selectively ignited at another time to produce a second pulse. Underbarrier igniters 72 (FIG. 13), or other forms of igniters such as electrical or pyrotechnic igniting devices, may be used to ignite a selected segment or grain of the propellant to initiate each pulse. Further, the propellant grains used for some or each of the multiple pulses may be formulated to exhibit the same or different burn rates. It is, of course, contemplated that more than two propellant grains pulses may be employed.